Improving Dynamic Range and Precision for Current-In-Plane Tunneling Measurements

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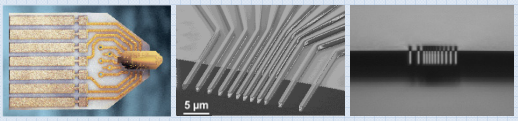
Motivation

Improved dynamic range and measurement precision by implementation of position correction algorithms

Micro 12-Point Probe



Probe info
- Length: 10µm
- Width: 0.75µm
- Thickness: 1µm
- 8 subsets of 4 electrodes
  - Mean pitches: 1.5µm – 8.3µm
- Electrode material: Au

4-Point Measurements on a Single Sheet

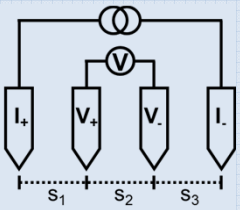
- Apply fixed current
- Measure voltage
- Extract sheet resistance

$$R_S = \frac{V}{I}\frac{2\pi}{\ln\left(\frac{bc}{ad}\right)}$$

a = distance between I_+ and V_+
b = distance between I_+ and V_-
c = distance between V_+ and I_-
d = distance between V_- and I_-

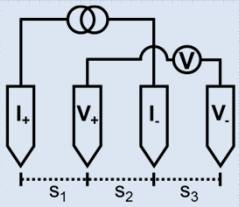
- Two independent 4-point configurations:

A-config



$$R_S = R_A\frac{2\pi}{\ln\left(\frac{(s_1+s_2)(s_2+s_3)}{s_1 s_3}\right)}$$

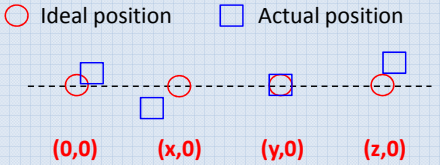
B-config



$$R_S = R_B\frac{2\pi}{\ln\left(\frac{s_2(s_1+s_2+s_3)}{s_1 s_3}\right)}$$

Positioning Errors

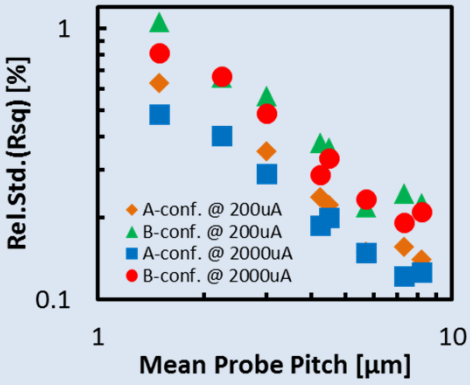
- Influences measured sheet resistance[1]
- Two types of positioning errors:
  - Inline (first order effect)
  - Offline (second order effect)



Position Correction on a Single Sheet

Experimental
- A and B-config measurements
- Current: 200µA and 2000µA
- Frequency: 25Hz
- Integration time: 81ms
- Scan: 10x10 points, step size: 100µm
- Sample: 200mm wafer, 100nm Ru
- $R_s \approx 1.6\Omega/\text{sq}$

Positioning Error (inline)
- A-config: $\sigma_{R_A}^{rel} = \frac{\sqrt{5}}{2\ln(2)}\frac{\sigma_x}{s} \approx 1.613\frac{\sigma_x}{s}$
- B-config: $\sigma_{R_B}^{rel} = \frac{4\sqrt{5}}{3\ln(3)}\frac{\sigma_x}{s} \approx 2.714\frac{\sigma_x}{s}$
- $\sigma_x \approx 5\text{nm}$



Two Position Correction Strategies
- Modified van der Pauw[2]

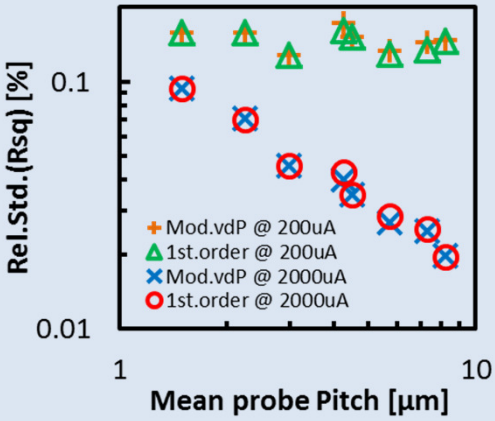
$$\exp\left(\frac{2\pi R_A}{R_S}\right) - \exp\left(\frac{2\pi R_B}{R_S}\right) = 1$$

- 1st. order approximation[3]

$$R_S = \frac{2\pi(R_A - \alpha R_B)}{\ln\left[\frac{y(z-x)}{x(z-y)}\right] - \alpha\ln\left[\frac{z(y-x)}{x(z-y)}\right]},$$

where $\alpha = \frac{z(y-x)}{y(z-x)}$

- Equal performance on a single sheet sample



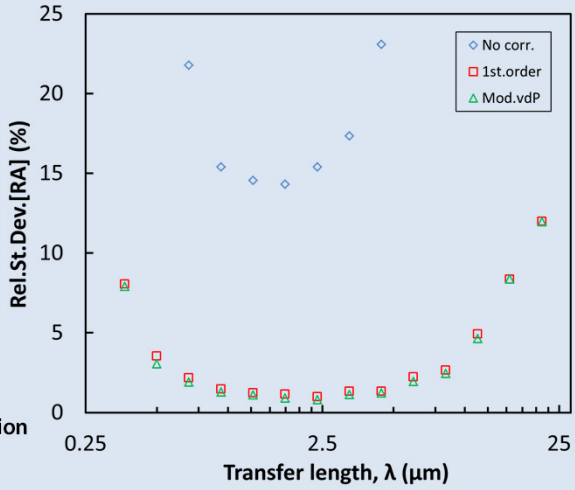
Position Correction for CIPT Measurements on MTJs

CIPT model[4]: $R = \frac{V}{I} = \frac{R_t R_b}{R_t+R_b}\frac{1}{2\pi}\left\{\frac{R_t}{R_b}\left[K_0\left(\frac{a}{\lambda}\right)+K_0\left(\frac{d}{\lambda}\right)-K_0\left(\frac{b}{\lambda}\right)-K_0\left(\frac{c}{\lambda}\right)\right]+\ln\left(\frac{bc}{ad}\right)\right\}$, where $\lambda = \sqrt{\frac{RA}{R_t+R_b}}$

MC-simulations
- $\sigma_x = 20\text{nm}$
- Electrical noise = 1%

Strategy (for each probe pitch):
1) Measure A-B-A-B
2) Calculate pseudo R_S
   - Mod.vdP
   - 1st. order approx.
3) Theoretical pseudo R_S
   - Based on Rt, Rb and RA
4) Minimize error by fitting Rt, Rb and RA

Conclusion:
Modified van der Pauw correction gives the best measurement precision and dynamic range



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